SEASONAL VARIATIONS IN SALINITY, DISSOLVED OXYGEN AND NUTRIENT SALTS IN THE INSHORE WATERS OF THE GULF OF MANNAR AND PALK BAY NEAR MANDAPAM (S. INDIA)

By R. Jayaraman*

(Central Marine Fisheries Research Station, Mandapam Camp)

CONTENTS

I. Introduction

A preliminary account of the chemical conditions of the inshore waters of the Bay of Bengal off Madras City has been given in an earlier paper by the author (1951). More detailed investigations in the same area have been reported by Ramamurthy (1953). An extension of similar studies to other typical centres has been considered desirable in order that a more comprehensive picture of the seasonal changes in the chemical conditions of coastal waters could be obtained. The present paper is an attempt to summarise the results of investigations carried out at inshore stations in the Gulf of Mannar and Palk Bay in the vicinity of Mandapam between the years 1950 to 1953.

II. Description of the Environment

In Fig. 1 is given a map of the region in which the studies reported in this paper have been carried out. The two areas, Gulf of Mannar and Palk Bay, lie respectively to the south and north of the narrow strip of the mainland of Mandapam. They have one common feature of being shallow, the depth not exceeding 6–7 fathoms even up to a distance of about 10 miles

* Present Address.—Offshore Fisheries Research Unit of the Central Marine Fisheries Research Stn., Sassoon Dock, Colaba, Bombay–5.

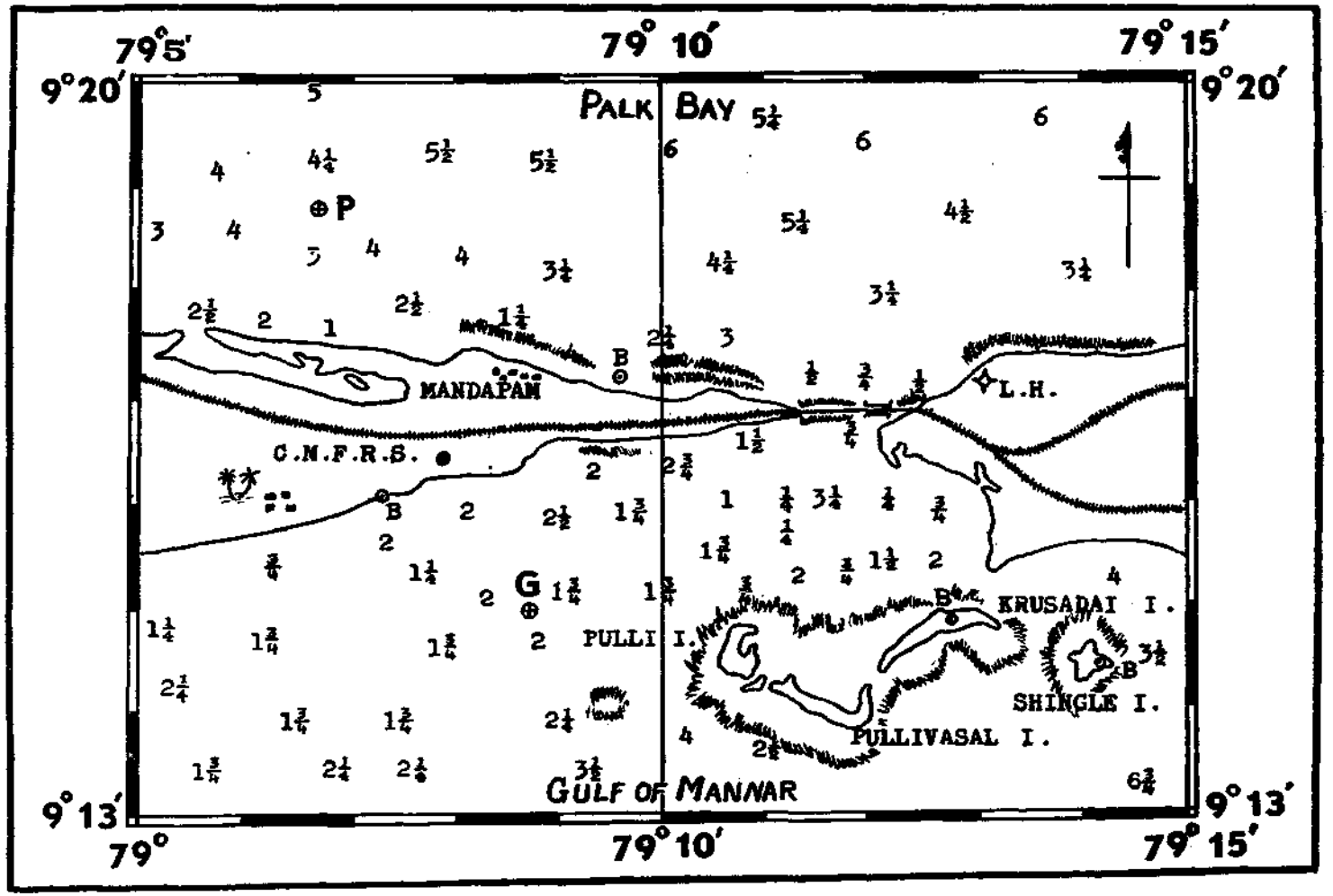

FIG. 1. Map of the inshore areas of the Gulf of Mannar and Palk Bay in the neighbourhood of Mandapam.

from the shore. The Palk Bay has a much larger shallow area than the Gulf of Mannar.

In the general hydrographical features there are a few differences between the two areas. A look at the Admiralty Chart for these areas (Chart 68-A) will show that while the Palk Bay is a more or less land-locked Sea, the Gulf of Mannar is more open. The inshore region of the Palk Bay is mostly muddy while in the Gulf of Mannar the inshore region is full of rocky patches with small areas of sand and mud in between. At distances ranging from 3–6 miles from the mainland of the latter, there is a chain of islands running roughly parallel to the coast. These islands are mainly of coral origin,

TABLE I

Gulf of Mannar—1950

Surface values

Month	Salinity S‰	Dissolved Oxygen ml./l.	Silicates μg. at Si/l.	Phosphates μg. at P/l.	Nitrates μg. at N/l.
January ..	28·85	4·59	5·5	0·24	2·2
February ..	30·05	4·48	7·0	·27	3·2
March ..	30·81	4·48	6·2	·20	2·6
April	33·56	4·04	7·0	·21	3·4
May	36·41	3·99	4·5	·21	2·2
June	35·53	4·18	5·8	·25	2·1
July	35·77	4·12	5·9	·28	1·1
August ..	36·34	4·00	4·8	·25	2·3
September ..	35·82	3·71	3·7	·22	1·1
October ..	35·89	3·53	4·8	·16	2·5
November ..	32·76	3·80	6·7	·17	2·5
December ..	29·44	4·21	6·9	·18	2·4
Bottom Values (Depth 2½ Fathoms)					
January ..	30·55	4·04	5·3	·30	2·4
February ..	31·55	4·15	6·5	·35	2·9
March ..	31·33	4·20	6·8	·24	3·6
April	34·08	3·81	7·4	·28	4·2
May	36·43	4·05	4·5	·23	3·4
June	35·54	4·18	5·7	·30	3·1
July	35·66	4·16	5·7	·29	2·1
August ..	36·34	4·00	4·5	·25	3·5
September ..	35·90	3·84	4·7	·24	1·8
October ..	35·95	3·65	4·6	·14	2·7
November ..	33·08	3·66	6·7	·17	3·1
December ..	30·36	4·09	6·4	·19	3·4

TABLE II

Gulf of Mannar—1951

Month	Salinity S‰	Dissolved Oxygen ml./l.	Silicates μg. at Si/l.	Phosphates μg. at P/l.	Nitrates μg. at N/l.
		Surface Values			
January ..	28·97	4·49	6·5	0·18	3·1
February ..	30·38	3·95	10·2	·19	2·6
March ..	31·54	3·52	9·6	·22	3·1
April	33·08	3·49	6·5	·17	2·7
May	..	..	..	..	..
June	..	..	..	..	..
July	35·81	3·46	6·0	·21	4·1
August ..	35·78	3·66	6·3	·19	3·3
September ..	36·02	3·78	5·0	·26	2·7
October ..	35·99	3·48	5·9	·23	3·4
November ..	33·96	3·74	7·9	·18	4·0
December ..	29·50	3·95	10·6	·18	3·4
		Bottom Values (Depth 2½ Fathoms)			
January ..	30·21	4·31	6·0	·21	4·1
February ..	31·76	3·94	8·6	·22	2·9
March	31·92	3·65	8·9	·19	2·7
April	33·11	3·62	6·2	·19	3·4
May	..	..	..	..	..
June	..	..	..	..	..
July	35·57	3·42	5·7	·21	4·4
August ..	35·82	3·77	5·9	·16	4·1
September ..	35·80	3·85	4·8	·22	3·7
October ..	35·98	3·66	5·1	·20	3·6
November ..	34·22	3·51	8·5	·18	4·1
December ..	29·37	4·15	10·5	·15	3·3

probably of the nature of fringing reefs, a full description of which is given by Devanesan and Chidambaram (1951). The waters in between these islands and the mainland are more shallow than those outside. The islands do not, however, form one continuous stretch. There are broad gaps between adjacent islands which establish continuity of the waters between the shallow and deeper portions of the sea. The presence of these islands has a great influence on the hydrological conditions of the inshore region of the Gulf.

The Palk Bay and Gulf of Mannar are not completely independent of each other. At their eastern extremity, the mixing of the waters of the two areas takes place through the Pamban Pass and also through the

TABLE III

Gulf of Mannar—1952

Month	Salinity S‰	Dissolved Oxygen ml./l.	Silicates μg. at Si/l.	Phosphates μg. at P/l.	Nitrates μg. at N/l.
		Surface Values			
January ..	29·29	4·40	6·0	0·18	3·6
February ..	30·62	3·50	7·9	·22	2·9
March ..	32·40	3·71	6·8	·30	3·5
April	32·81	..	..	·13	2·9
May	34·67	3·60	6·3	·15	2·5
June	35·27	3·54	8·9	·27	1·9
July	34·78	3·57	14·8	·21	2·4
August ..	36·42	4·08	8·1	·24	2·1
September ..	36·47	3·93	9·2	·18	2·5
October ..	36·45	3·86	14·6	·16	2·3
November ..	31·77	4·23	13·1	·25	2·6
December ..	27·47	3·34	18·3	·09	3·0
		Bottom Values (Depth 2½ Fathoms)			
January ..	29·89	4·46	5·8	·18	4·2
February ..	30·88	3·50	7·9	·22	3·1
March ..	32·58	3·67	6·8	·22	3·7
April	32·63	..	..	·13	3·9
May	33·90	3·60	6·3	·15	2·3
June	35·27	3·52	6·0	·21	2·5
July	34·65	3·57	11·5	·18	2·7
August ..	36·29	4·08	6·1	·19	2·9
September ..	36·29	3·50	7·3	·14	3·3
October ..	36·41	3·94	14·3	·17	2·3
November ..	31·72	4·29	12·8	·24	2·2
December ..	28·47	3·09	13·9	·10	2·7

"Adam's Bridge" between Dhanushkodi and the west coast of Ceylon. This mixing or "exchange" is of great importance in bringing about similarity in the hydrological conditions during certain seasons of the year.

The total annual rainfall of this region is about 30 inches, most of it falling during the North-East monsoon months, November–January. The surface temperature of the waters of the Gulf of Mannar has an annual range between 25° C. and 30° C. No complete data are available on the surface temperatures of the Palk Bay waters. A few isolated observations, however, reveal that the surface temperature of the Palk Bay waters is somewhat of a lower order than that of the Gulf of Mannar, although the differences

TABLE IV

Palk Bay—1951–52

Month	Salinity S‰	Dissolved Oxygen ml./l.	Silicates µg. at Si/l.	Phosphates µg. at P/l.	Nitrates µg. at N/l.
		Surface Value			
May	32·16	2·90	5·3	0·17	2·7
June	33·50	1·70	..	..	4·8
July	34·73	3·12	7·1	·14	3·6
August ..	35·26	3·37	6·7	·15	3·6
September ..	35·76	3·09	9·8	·23	4·6
October ..	36·07	3·26	7·5	·22	3·5
November ..	33·21	2·99	13·2	·24	4·6
December ..	29·43	3·55	8·8	·22	5·0
January ..	28·53	3·80	7·9	·21	4·4
February ..	29·58	3·12	8·0	·21	3·6
March ..	30·88	3·11	5·3	·18	3·8
April ..	32·01	3·00	7·1	·18	4·2
		Bottom Value (Depth 3½ Fathoms)			
May	32·43	2·90	5·9	·24	3·6
June	33·36	1·80	..	..	5·1
July	34·59	3·10	7·3	·16	4·2
August ..	35·17	3·37	7·1	·16	4·3
September ..	35·69	3·32	9·0	·20	3·8
October ..	35·92	3·44	7·4	·20	3·9
November ..	33·93	2·96	12·1	·23	5·0
December ..	29·43	3·46	8·3	·16	5·0
January ..	28·38	3·73	7·3	·19	4·9
February ..	29·47	3·22	8·0	·21	3·9
March ..	30·88	3·31	5·1	·17	3·7
April	31·92	2·99	6·2	·16	3·4

do not appear to be quite significant. The only current systems of major importance are those caused by the South-West and North-East monsoons.

III. MATERIAL AND METHODS

(*a*) *Collection of water samples.*—The collections of water samples were made at the inshore stations (G and P in the map) in the two areas situated at a distance of about 2 miles from the shore. The depth of water at G is about 2½ fathoms and at P is about 3½ fathoms. The surface samples of water were obtained directly by dipping a glass bottle with the usual precautions to exclude air and the bottom samples with a Casella bottle. It

TABLE V

Palk Bay—1952–53

Month	Salinity S‰	Dissolved Oxygen ml./l.	Silicates μg. at Si/l.	Phosphates μg. at P/l.	Nitrates μg. at N/l.
		Surface Values			
May	33·04	2·97	8·0	0·16	3·0
June	33·75	3·62	10·7	·25	2·6
July	33·96	3·33	14·0	·20	2·8
August ..	35·21	3·39	10·2	·18	3·0
September ..	35·91	3·64	9·3	·18	2·9
October ..	36·39	2·93	17·9	·20	3·2
November ..	33·12	3·43	11·9	·21	2·9
December ..	27·59	4·40	..	·14	3·8
January ..	25·52	3·96	10·2	·18	3·5
February ..	27·25	2·96	9·0	·21	3·7
March ..	29·98	2·88	9·7	·17	3·1
April	31·60	2·51	8·8	·17	2·3
		Bottom Values (Depth 3½ Fathoms)			
May	33·06	3·08	7·8	·16	3·1
June	33·65	3·56	9·5	·18	3·4
July	33·90	3·36	12·5	·17	3·1
August ..	35·16	3·50	8·6	·17	2·9
September ..	35·91	3·62	6·5	·16	3·2
October ..	36·27	3·13	17·0	·17	3·2
November ..	32·98	3·48	10·7	·19	2·8
December ..	27·41	4·56	..	·08	3·3
January ..	25·29	3·91	8·1	·19	3·2
February ..	27·09	3·25	7·4	·20	3·7
March ..	29·97	3·13	8·2	·15	3·8
April	31·57	2·71	8·2	·17	3·9

has been found that for shallow areas, the casella type of bottle could be used with advantage.

The schedule of sampling was three times a week and all collections were made in the early hours of the morning between 6 and 7 A.M.

From January 1950 to the end of April 1951 all three collections during a week were obtained from the inshore station in the Gulf of Mannar. The routine was altered from May 1951 so that every week two collections were made from Palk Bay and one from the Gulf of Mannar. Bad weather conditions occasionally upset the sampling schedule.

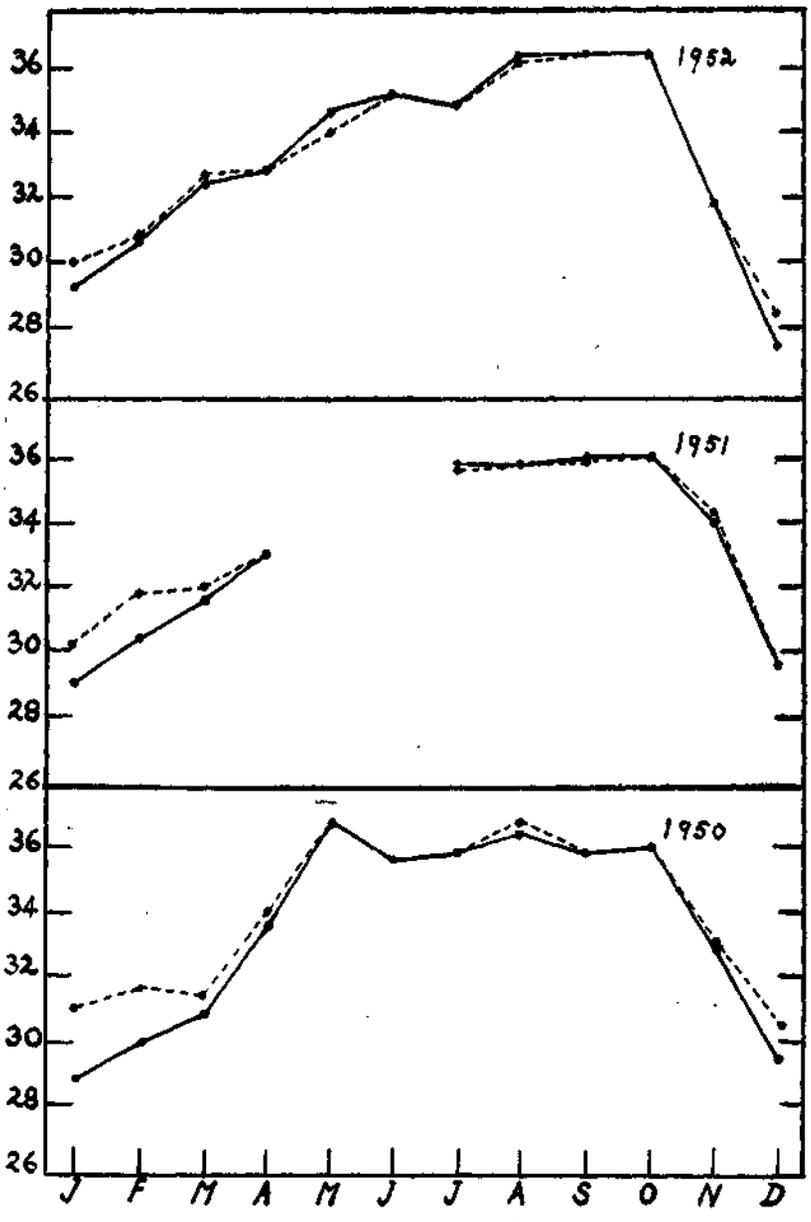

FIG. 2. Showing the monthly distribution of Salinity in the Gulf of Mannar from January 1950 to December 1952.

Salinity expressed as parts per thousand.

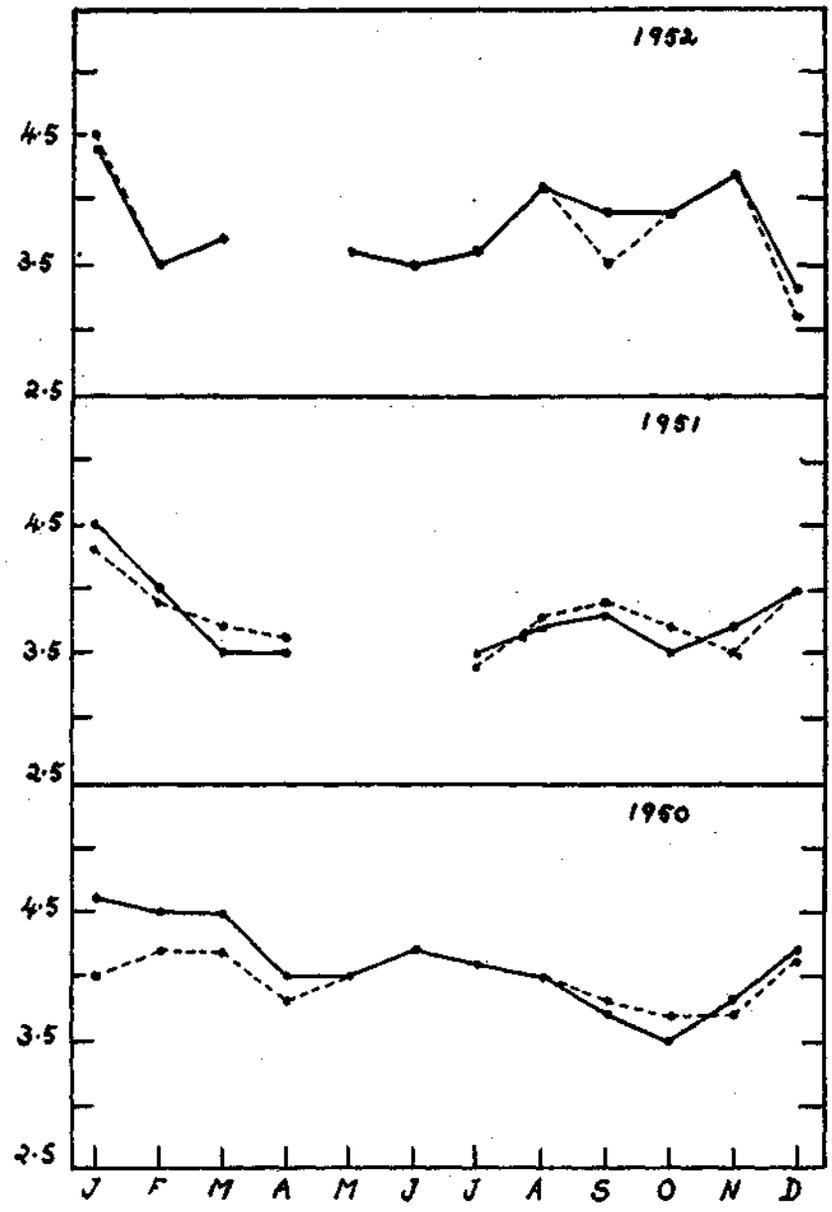

FIG. 3. Showing average monthly values for dissolved Oxygen in the Gulf of Mannar from January 1950 to December 1952.

Oxygen content expressed as ml./L.

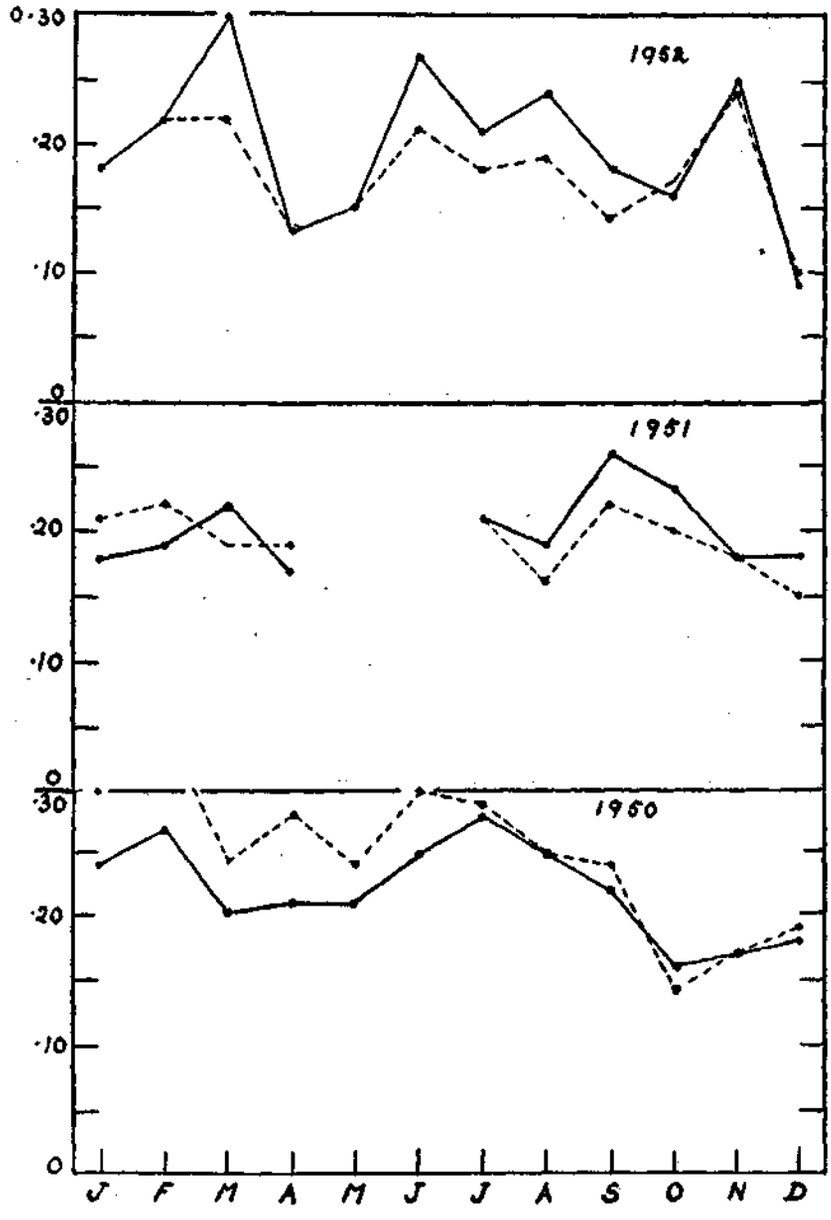

FIG. 4. Showing the average monthly values for Phosphates in the Gulf of Mannar from January 1950 to December 1952.

Phosphates expressed as μg-at. P/L.

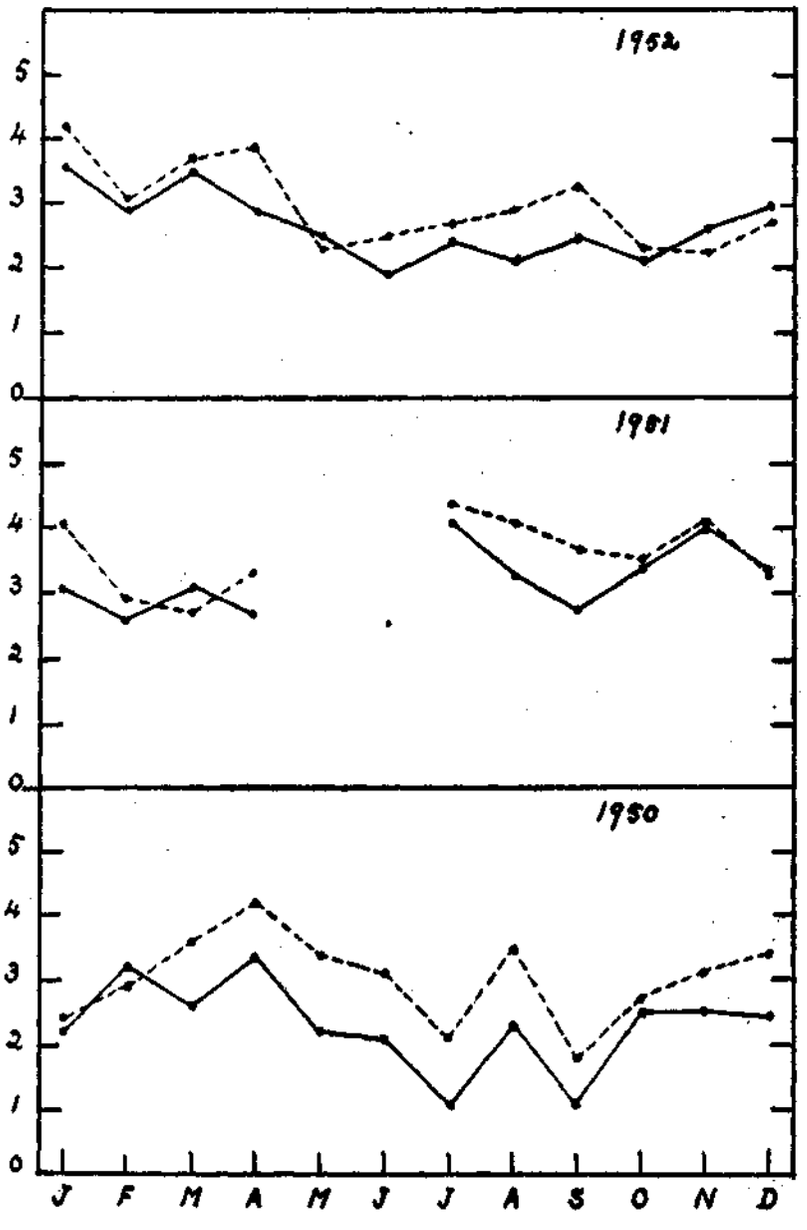

FIG. 5. Showing the average monthly concentrations of Nitrates in the Gulf of Mannar from January 1950 to December 1952.

Nitrates expressed as μg-at. NO_3- N/L.

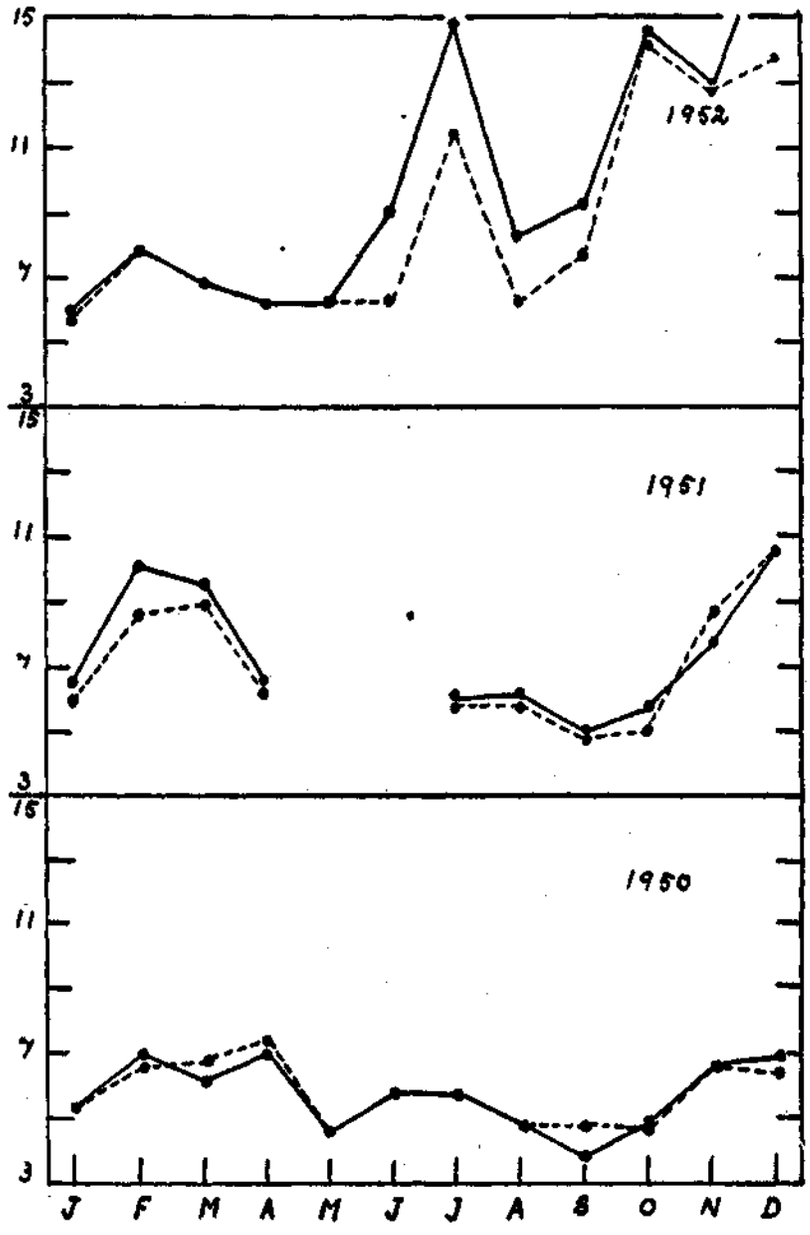

FIG. 6. Showing the average monthly concentration of Silicates in the Gulf of Mannar from January 1950 to December 1952.

Silicates expressed as μg-at. Si/L

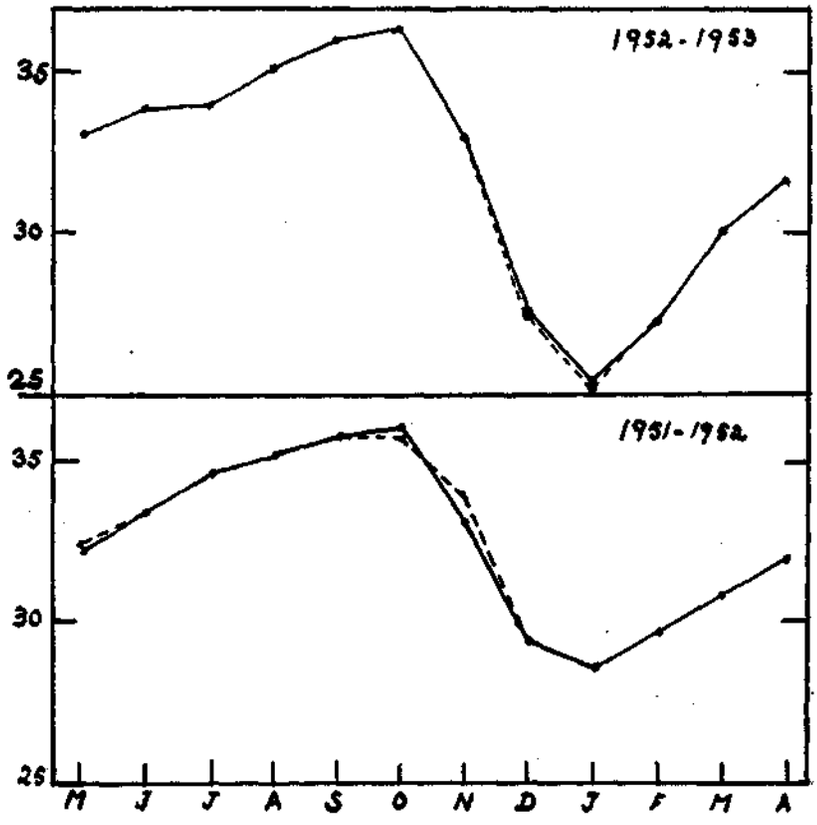

FIG. 7. Showing the monthly distribution of Salinity in the Palk Bay from May 1951 to April 1953.

Salinity expressed as parts per thousand.

(*b*) *Methods of Analysis.*—The analytical procedures outlined by the author in the previous paper (1951) were followed without any modifications.

IV. RESULTS

Tables I–V give the monthly averages which are also shown in the form of graphs (Figs. 2–11).

V. DISCUSSION

(i) *Salinity*

The graphs showing the average monthly salinities represent regular seasonal cycles of salinity in these waters. Similar cycles in the salinity have been reported in the waters of the Bay of Bengal off Madras City (Jayaraman, 1951; Ramamurthy, 1953).

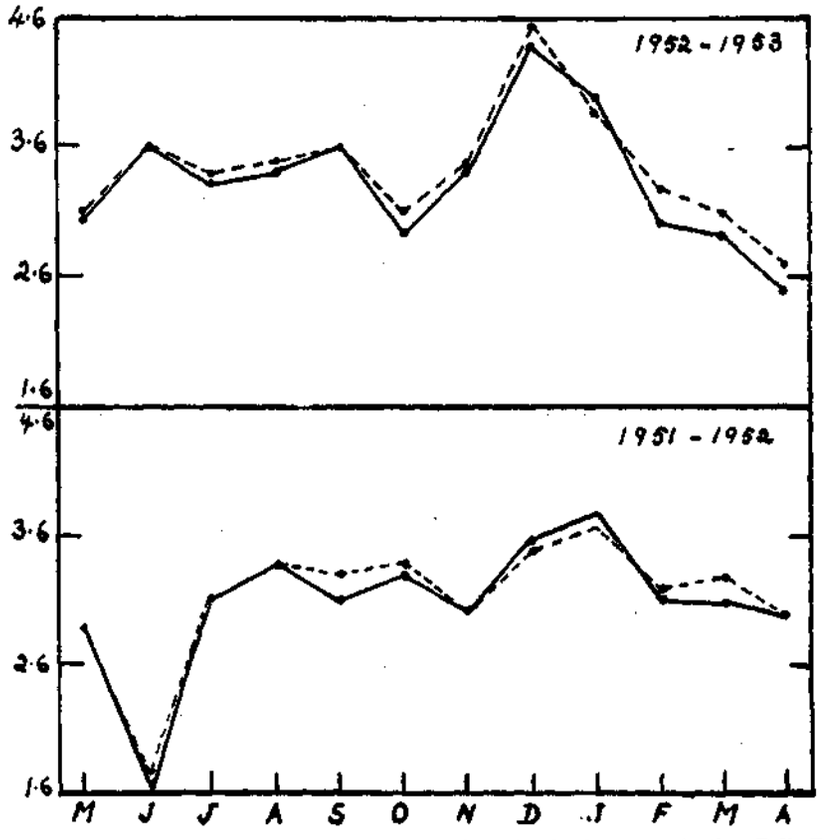

FIG. 8. Showing the average monthly values for dissolved oxygen in the Palk Bay from May 1951 to April 1953.

Oxygen content expressed as ml/L.

The mean annual range of salinity is 7·4‰ for the waters of the Gulf of Mannar and 9·0‰ for those of the Palk Bay. There are, however, deviations from these mean values in the various years; the maximum annual range in salinity has been observed in the year 1952.

High values for salinity are observed in the period, May–October, while low values are to be found between November and April. It may be noted that the earlier months of these two periods coincide with the two monsoons, South-West and North-East. Thus it is seen that salinity is high during the months of the South-West monsoon and low during those of the North-East monsoon.

The most important factors governing the seasonal distribution of salinity in these waters are the two monsoon-driven current systems mentioned earlier. During the period of the South-West monsoon, the direction

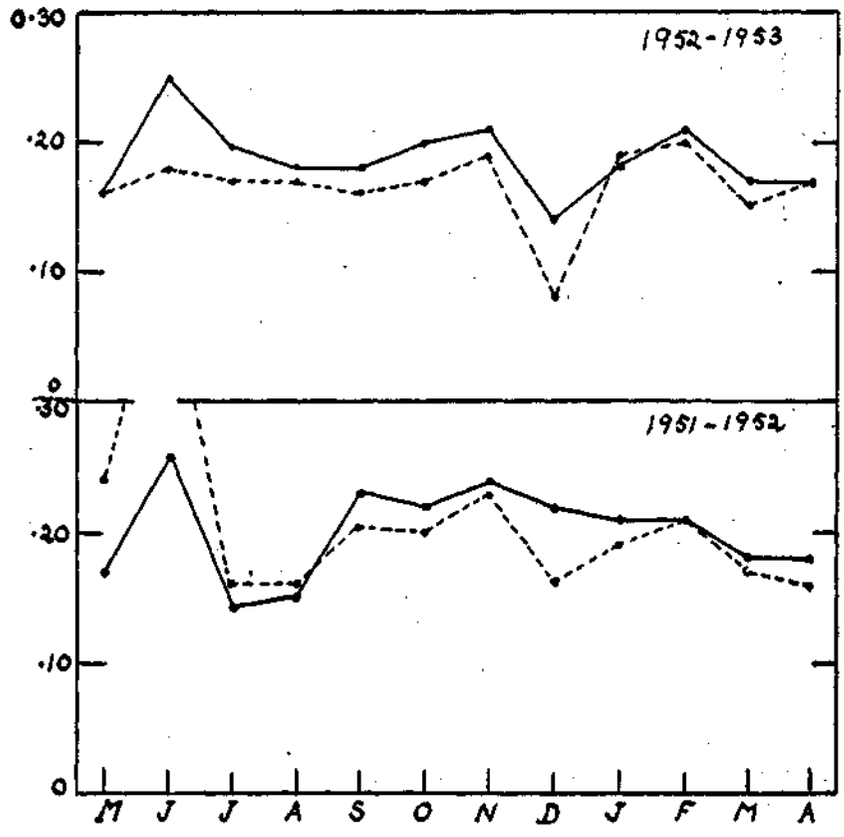

FIG. 9. Showing the average monthly values for Phosphates in the Palk Bay from May 1951 to April 1953.

Phosphates expressed as μg-at. P/L.

of the current is from South to North in this region (Sewell, 1925–32). This current brings in large amount of "oceanic" water from the Indian Ocean and also from the southern part of the Arabian Sea. As these waters have a high salinity—of the order of 34·5–35·0‰—there is a general rise in the salinity of the waters of the Gulf of Mannar and Palk Bay. Due to the prevalence of high winds and to the rather high atmospheric temperature, there is a certain amount of evaporation which causes a further rise in the salinity of the shallow inshore waters. A maximum value of 36·5–37·0‰ is reached usually towards the end of September and in early October. The salinity maximum is observed earlier in the Gulf of Mannar than in the Palk Bay.

With the onset of the North-East monsoon, there is a marked change in the conditions. The direction of current is reversed, the flow being from

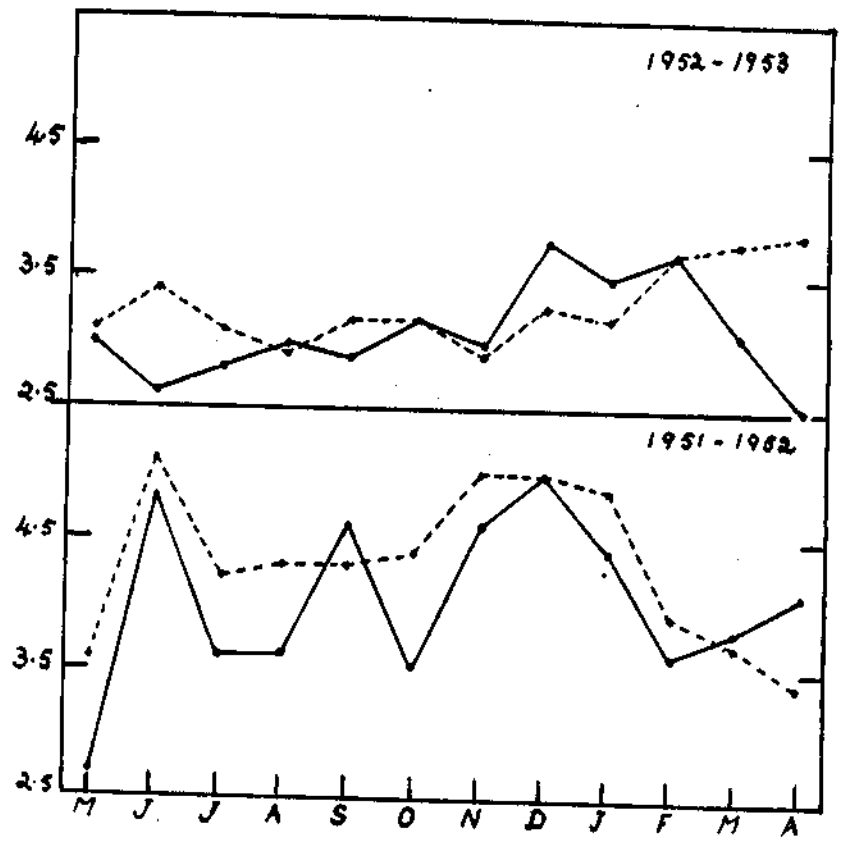

FIG. 10. Showing the average monthly concentrations of Nitrates in the Palk Bay from May 1951 to April 1953.

Nitrates expressed as μg-at. No_3 N/L.

the North to the South (Sewell, *loc. cit.*). There is an influx of water of low salinity from the North which markedly lowers the salinity of these waters. Values as low as 24·0–27·0‰ have been recorded during the months of December and January. By the end of February, when the strength of the influx is considerably diminished, the salinity begins to increase. It has been observed that the lowering in salinity occurs almost in the same period in the different years.

Sub-surface salinity measurements have revealed small vertical salinity gradients in both the areas, the difference between surface and bottom being seldom more than 1‰. The stratification is generally observed during the calm months following the monsoons, particularly during the period of low salinity.

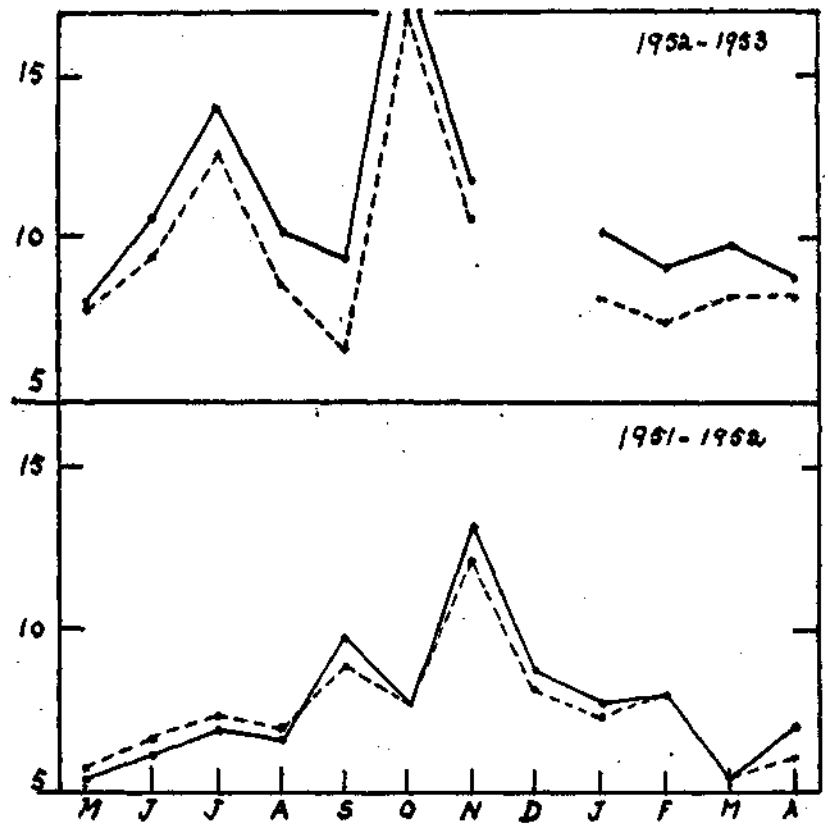

FIG. 11. Showing the average monthly concentration of Silicates in the Palk Bay from May 1951 to April 1953.

Silicate expressed as μg-at. S/L.

(ii) *Dissolved Oxygen*

The seasonal distribution of dissolved oxygen in these waters shown in Figs. 3 and 8 shows no marked variations in the oxygen content in the various months, and that during most of the year the waters are far from being saturated with oxygen.

The monthly averages for the oxygen values range between 3·5 and 4·5 ml./l. for the Palk Bay. Deviations from these ranges are more common in the Palk Bay than in the Gulf of Mannar. In comparing the two areas it is seen that in the Palk Bay waters there are much greater variations in the oxygen content than in the waters of the Gulf.

The surface-bottom differences in the dissolved oxygen content are not at all appreciable in the two areas, probably because of " vertical mixing " which is characteristic of shallow waters.

(iii) *Nutrient Salts*

(*a*) *Phosphates.*—The mean monthly values for phosphates in the Gulf of Mannar vary between 0·15 and 0·30 μg. at P/l. (4·7–9·3 mg. P/C. metre) and in the Palk Bay, between 0·12 and 0·25 μg. at P/l. (3·7 to 7–7 mg. P/C. metre). It is to be noted that the level of phosphates in these waters is far below that observed in the waters of the higher latitudes. Similar low values have been reported by Orr (1928–29) for the waters of the Great Barrier Reef Lagoon—the average phosphate content of those waters being of the order of 4·0 mg. P/C. metre. Such low values combined with the absence of marked seasonal cycles may point to a low level of organic production in these waters. Delsman (1939) is, however, of the opinion that " from low phosphate values alone it cannot be emphatically stated that the area is very poor; it is quite probable that much more rapid metabolism in the tropical seas check such accumulation of nutrient substances as occur in most Northern waters during the winter". Although the level of phosphates in the Gulf of Mannar and Palk Bay is low, there has been at no time of the year total exhaustion of this constituent.

(*b*) *Nitrates.*—Unlike the phosphates the nitrates show much greater seasonal fluctuations in these waters. On some occasions nitrates are either totally absent or present only in negligible quantities.

These two facts, namely, marked seasonal variations as well as occasional depeletion of nitrates show that besides the usual channel of utilization of nitrates by the phytoplankton, there is an equally significant factor which controls their concentration in these waters. It is possible that denitrifying bacteria are present in these shallow environments, utilising the inorganic nitrates for their energy requirements and that the nitrates in their turn are progressively reduced to gaseous nitrogen. Their presence has also been demonstrated under laboratory conditions (N. K. Velankar, private communication). It therefore, appears quite likely that the seasonal variations in the nitrate content may also be due partly to the fluctuations in the number and activity of the denitrifiers. It has, however, to be borne in mind that the denitrifiers occur in more or less restricted areas subject to the influence of land drainage.

(*c*) *Silicates.*—The annual range of silicates in both the areas is of the order of 15·0 μg. at Si/l. (900 mg. SiO_2/C. metre), the highest and lowest being 20·0 and 5·0 μg. at Si/l. (1,200 and 300 mg. SiO_2/C. metre). Values as high as 30·0 μg. at Si/l. (1,800 mg. SiO_2/C. metre) and as low as 3·0 μg. at Si/l. (180 mg. SiO_2/C. metre) have occasionally been obtained. In comparing

the two areas, it is seen that the total annual turnover of silicates is far higher in the Palk Bay than in the Gulf of Mannar.

As in the case of salinity, the seasonal distribution of silicates is very much influenced by the presence of the two current systems; the incursion of the "oceanic" type of water brings about marked reduction, while the fresh-water influx causes an increase in the silicates. There is in general, an inverse relationship between silicates and salinity as has been observed previously in the Madras waters. It may be seen, however, that during the period, June-October 1952, this relationship had been upset when along with high salinity very high concentrations of silicates were observed. During the same period swarms of *Noctiluca* were seen in the plankton collections. A possible association between this "swarming" and the marked increase in the silicates has been indicated in detail elsewhere (Prasad and Jayaraman, 1953).

VI. Summary

Data on the seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay between the years 1950–53 have been presented and discussed.

Salinity shows a regular seasonal cycle corresponding to the South-West and North-East monsoons.

Dissolved oxygen content values are steady during most of the year and the surface-bottom differences in the oxygen content are not quite appreciable. The oxygen values are far below the saturation limit.

Phosphates are low and do not show much seasonal variation.

Nitrates show wider variations due probably to the activity of the denitrifying bacteria.

Silicates show the usual inverse relationship with salinity except during the period, June-October in the year 1952. It is suggested that there is a possible association of these conditions with the swarming of *Noctiluca* observed during the same period.

VII. Acknowledgements

The author wishes to express his thanks to Dr. N. K. Panikkar, Chief Research Officer, for his advice and interest in these investigations as well as in the preparation of this paper, and to Dr. Raghu Prasad, Marine Biologist, and Shri N. K. Velankar, Bacteriologist, for helpful discussions in the course of this work.

VIII. REFERENCES

1. Admiralty Chart 68-A .. "Palk Strait and Gulf of Mannar".
2. Delsman, H. C. .. "Preliminary Plankton Investigations in the Java Sea", *Treubia*, 1939, **17** (2) 139-82.
3. Devanesan, D. W. and Chidambaram, K. "Report on Pearl Oyster," 1951 (Unpublished).
4. Jayaraman, R. .. "Observations on the chemistry of the waters of the Bay of Bengal off Madras City during 1948-49," *Proc. Ind. Acad. Sci.*, 1951, **33B**, 92-99.
5. Orr, A. P. .. "Physical and Chemical conditions in the sea in the neighbourhood of the Great Barrier Reef," *Great Barrier Reef Expedition Reports*, 1928-29, **2** (i).
6. Prasad, R. R. and Jayaraman, R. "Preliminary studies on certain changes in the Plankton and Hydrological conditions associated with the swarming of *Noctiluca*," 1953 (in the course of publication).
7. Ramamurthy, S. .. "Hydrobiological Studies in the Madras coastal waters," *J. Madras Univ.*, 1953, **23B** (2), 148-63.
8. Sewell, R. B. S. .. "Geographical and Oceanographial Research in Indian waters," *Mem. Asia. Soc., Bengal*, 1925-32, **9**, 1-424.